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Summary Report for the Microwave Source Working Group

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Abstract

This report summarizes the discussions of the Microwave Source Working Group during the Advanced Accelerator Concepts Workshop held October 13-19, 1996 in the Granlibakken Conference Center at Lake Tahoe, California. Progress on rf sources being developed for linear colliders is reviewed. Possible choices for high-power rf sources at 34 GHz and 94 GHz for future colliders are examined.

INTRODUCTION

In the past few workshops much of the work by this group focused on providing a X-band power source for a 1-TeV electron-positron linear collider system. SLAC started a serious effort on high-peak power X-band sources in the mid 1980s. The successful demonstration of an efficient 50-MW X-band tube this summer by SLAC shifts the emphasis of this group to the power source for future accelerators beyond the NLC.

These proceedings include an excellent review of the microwave source development for colliders by W. Lawson [1] and many contributed papers on individual research efforts by members of the working group. This summary will concentrate more on the issues that were discussed by the working group.

RESEARCH EFFORTS ON DISCRETE RF POWER SOURCES

SLAC's PPM klystron tube is the best choice for the NLC rf power source. However, a number of the X-band rf sources being studied have the potential to improve the efficiency of future collider systems or to lower their cost. The following is a brief report of the status of the research efforts on discrete sources by members of the group with references to where additional information can be found.

PPM klystron tube - SLAC in July 1996 successfully demonstrated [2] that the PPM klystron tube could produce 56 MW of 11.4 GHz power in a 1.2 μsec pulse. Work on the beam transport using periodic permanent magnets (PPM) went smoothly after several years of working on the design of the output structure. The tube shows 60% electronic efficiency, close to that predicted by CONDOR. The beam loss in the tube is small over an acceptable voltage spread. There are still a number of "engineering" issues for the tube that will be studied. Since almost 10,000 tubes are planned for 1-TeV NLC operation construction techniques are being considered to reduce the tube cost. It is expected that this type of tube will satisfactorily provide the rf power for the NLC.

Cluster klystron - Experiments during the past year at BNL [3] on the cluster klystron concept have focused on the creation of the annular electron beam which will be needed in the device. The close packing of the tubes does not allow for use of a high cathode-to-beam compression ratio as in many of the other devices. This places a difficult requirement on the MIG guns being proposed for the system. The pulsed power for the test device has been prepared and cathode testing should start soon.

Sheet-beam klystron - None of the workshop participants were working on the sheet beam klystron approach, however this device [4] is seen as a possible efficient rf source in the higher frequency collider schemes.

Magnicon - The work at NRL [5] and INP [6] on magnicons was reported during the workshop. Magnicons have the advantage of lowering the energy density from that of a high power X-band klystron. They have shown impressive results at low frequency, but experiments at X-band have shown that better vacuum and microwave techniques are required to reduce pulse shortening. NRL is working on a new magnicon with a thermionic cathode for which simulations have shown good performance.

TWT - Cornell University's recent simulations [7] have shown that the efficiency of their device can be increased to about 50% by an appropriate phase velocity transition in their interaction structure and the use of a coaxial extraction circuit. The group has also made good progress on the control of side-bands in their device.

Gyroklystron - Experimental efforts at the University of Maryland have focused on a 2nd harmonic gyroklystron [8] for which simulations have shown 158 MW at 17.1 GHz for a 1.2 μsec pulse. The expected increase in rf output power is from careful attention paid to the gun and transport systems.

Gyroharmonic Converters - Yale/Omega-P is working on a cyclotron autoresonance acceleration (CARA) [9] device. In this device rf power is used to "energize" an electron beam. RF power can then be extracted from the beam at a higher harmonic. They have examined a system where a 2.856 GHz drive source could be used to provide 30 GHz rf power (7th harmonic).

Cyclotron Resonance Klystron - UC Davis is proposing a device that uses an FEL interaction to bunch the electron beam, and a klystron like output cavity for power extraction.

Ubitron - Work around 1960 on ubitrons produced tubes that ranged up to 50 GHz. Promising conceptual work [10] on a 280-MW, 11.4-GHz system has been done at SLAC and UC Davis. A thin annular beam is required in this device. The 2.3 meter design length is more compact than standard FEL devices. The 11.4-GHz device uses a 500-kV 1-kA thin annular beam.

FEMs - LANL has started construction of a novel 17-GHz free-electron maser (FEM) [11]. The beam interacts with rippled walls, instead of the normal wiggler magnetic field. Simulation has shown rf power production of 500 MW using a 5-kA, 600-kV beam source.

TWO-BEAM ACCELERATORS

To demonstrate the efficacy of the two-beam accelerator concept the two major efforts are constructing test facilities which include prototype modules for their larger systems. In these schemes high conversion efficiencies of wall power to beam power will only be seen in the larger systems. Work on the two-beam accelerator schemes is summarized [12] by an invited talk by R. Corsini.

Several new options for the creation of the drive beam for CERN's two-beam accelerator scheme were discussed. The effects of short field wakes from the transfer structures in the drive beam are better understood, and a solution is being demonstrated in the CTF test facility [13]. The test facility will address many of the issues of rf power generation using the CLIC approach.

The major effort of LBL/LLNL's two beam accelerator approach is to provide an upgrade to the NLC power sources at 11.4 GHz. Work on establishing the test facility[14] and rf cavity design [15] was reported on during the workshop. With minor variation, the test facility could provide power up to 34 GHz. A study for a 5-TeV collider at 30 GHz using induction-driven two-beam accelerator was presented [16]. Additional studies of the wake fields in the rf output structures and in the main accelerator at these higher frequency scheme is needed for this study. Two-beam accelerator schemes using a FEL interaction could operate at even higher frequencies.

WORK AT 34 GHZ

There are compelling reasons [17,18] that push the designs of high-energy room-temperature electron-positron linear colliders to higher frequencies. Several studies have suggested that for a 5-TeV center-of-mass energy the optimal linac operating frequency is in the 30 to 35 GHz range. However, in choosing the frequency, each of the studies has made some questionable assumptions with regard to the rf source. A challenge for the working group was to examine possible rf power sources at 34.3 GHz (12 times SLAC's operating frequency). Many of the fast wave devices (i.e. gyroklystron, FELs) and the two-beam accelerator systems are already designed for frequencies above 11.4 GHz and could be scaled to the 34 GHz. A design for 35-GHz gyroklystron was presented [19].

During the workshop SLAC presented an interesting 50-MW klystron design at 34 GHz with 40% efficiency. It uses a 620-kV, 240-A electron beam. The required guide field of 2.7 kGauss would be too high for PPM focusing. The only high power (>10MW) klystrons above 3 GHz are those being developed for linear colliders. Besides SLAC and KEK tubes at 11.4 GHz, there is the VLEPP tube at 14 GHz and the HRC tube at 17.1 GHz.

Some initial thoughts on scaling TWTs and magnicons and other devices were also done by the workshop participants. Overall, there is no clear choice on which device will give the best performance at 34 GHz. We expect that additional simulation work will be performed before the next workshop on 34 GHz rf sources.

W-BAND SOURCES

During the last year there has been growing interest in the development of 94 GHz (W-band) accelerator structures. Many components exist for operation in this band for radar applications, however there is a shortage of high peak power sources. Critical issues to be studied involve surface heating effects in the accelerating structures for these short wavelengths at high gradients. Initial experiments do not require that the rf source be efficient. However, the final choice of optimal frequency for a future collider depends on suitable efficient rf sources. In the higher energy machine overall system efficiency of wall-plug to beam will become even more important.

Gyrotrons have already produced high average power in this frequency range. For 500-ms pulses they have produced 0.68 MW of rf power. The goal would be to increase the peak power to about 100 MW for shorter pulse widths (~1μs). The highest power produced in the gyroklystron experiment at University of Maryland has been 32 MW at 20 GHz. A rough estimate indicates that 50 MW of rf power at 100 GHz could be produced using gyroklystrons. The efficiency was estimated at 15% for this device without energy recovery, and 37% for a single depressed-collector system.

Free-electron lasers (FELs) are another possible candidate for a laboratory high peak power source. LLNL produced about 2 GW of rf power at 140 GHz with about 20 ns duration [20]. A smaller system at MIT produced 61 MW for 30 ns pulses at 33 GHz [21]. A recommendation is that the issues of phase stability and cost be reviewed for using a FEL as a driver in this frequency range. A fast-forward feedback circuit [22] could reduce some of the earlier concerns with systematic phase variations.

TECHNOLOGIES

During the workshop several technologies were discussed that could improve the performance of rf sources for accelerator applications in general. The following is brief summary of a few of these ideas.

RF Pulse Compression

An area of exciting research involves schemes to improve the efficiency of pulse compressors with high compression ratios. This would allow a low-power tube to deliver the high peak powers which are needed for high-gradient accelerators. SLAC has recently demonstrated efficient high-power pulse compression [23] for NLC. They are attempting to increase the efficiency of SLED by introducing an appropriate phase shift in the delay lines [24]. OMEGA-P also presented a scheme based on closing switches [25].

Electron Source Development

Advances in cathode technology could enable new rf power sources. The generation of the required annular beams in many of the devices discussed (i.e. cluster klystron, gyroklystron, ubitron, FEMs) are viewed as a major issue in their development. Even in the "conventional" klystron tube the cathode is a major consideration for the tube lifetime.

Work on several electron sources was discussed at the workshop. Cornell is investigating ferroelectric cathodes [26]. They have obtained long pulse operation with their sources. However, the electron from the longer pulses may be from plasma emission. Work on an electron sources using secondary electron emission was reported on by FMT [27]. These have shown stable operation and have produced good low-emittance beams. Work has started on long-life high-current oxide cathodes at SLAC.

Cavity wall coatings

Another technology that promises to have a major impact on rf sources is cavity coating to increase the breakdown voltage level and/or lower multipactoring. Coating have been found that have good DC breakdown holdoff, low rf absorption, and are physically rugged. Hot testing in a klystron output structure should take place within the next few months. The coating in DC tests had a substantial effect on reducing dark-current emission.

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